CrIS Calibration Reference Uncertainty (ICT vs. ECT)

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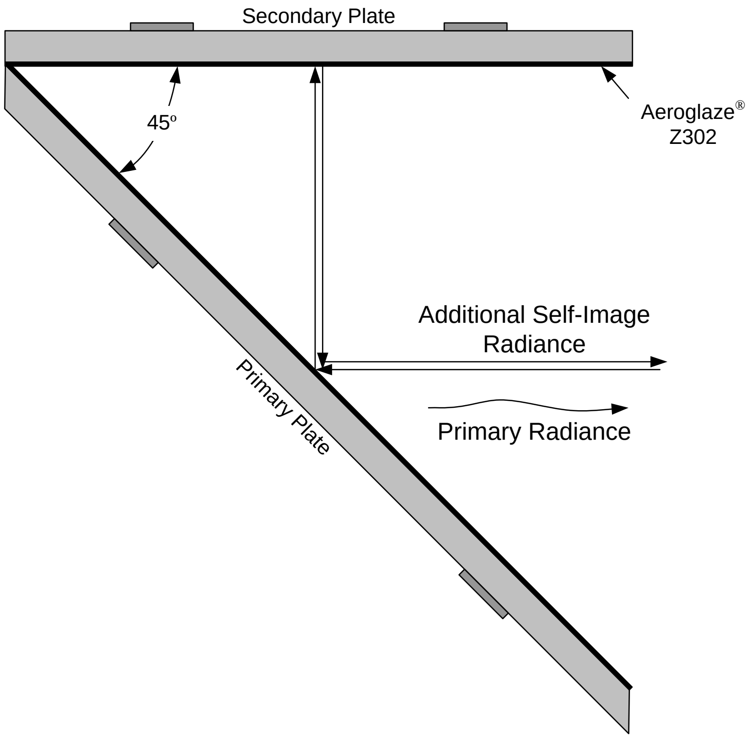
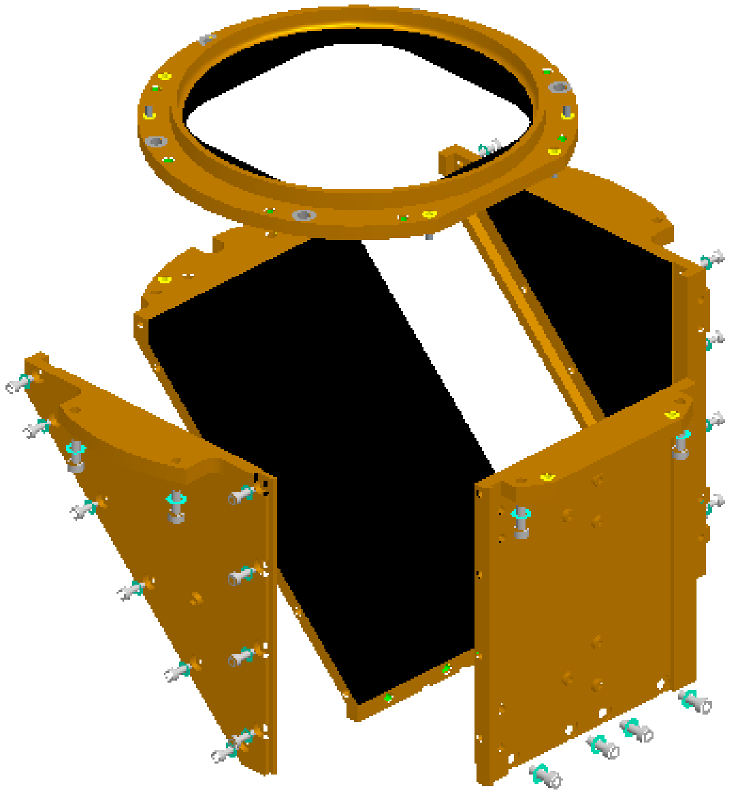
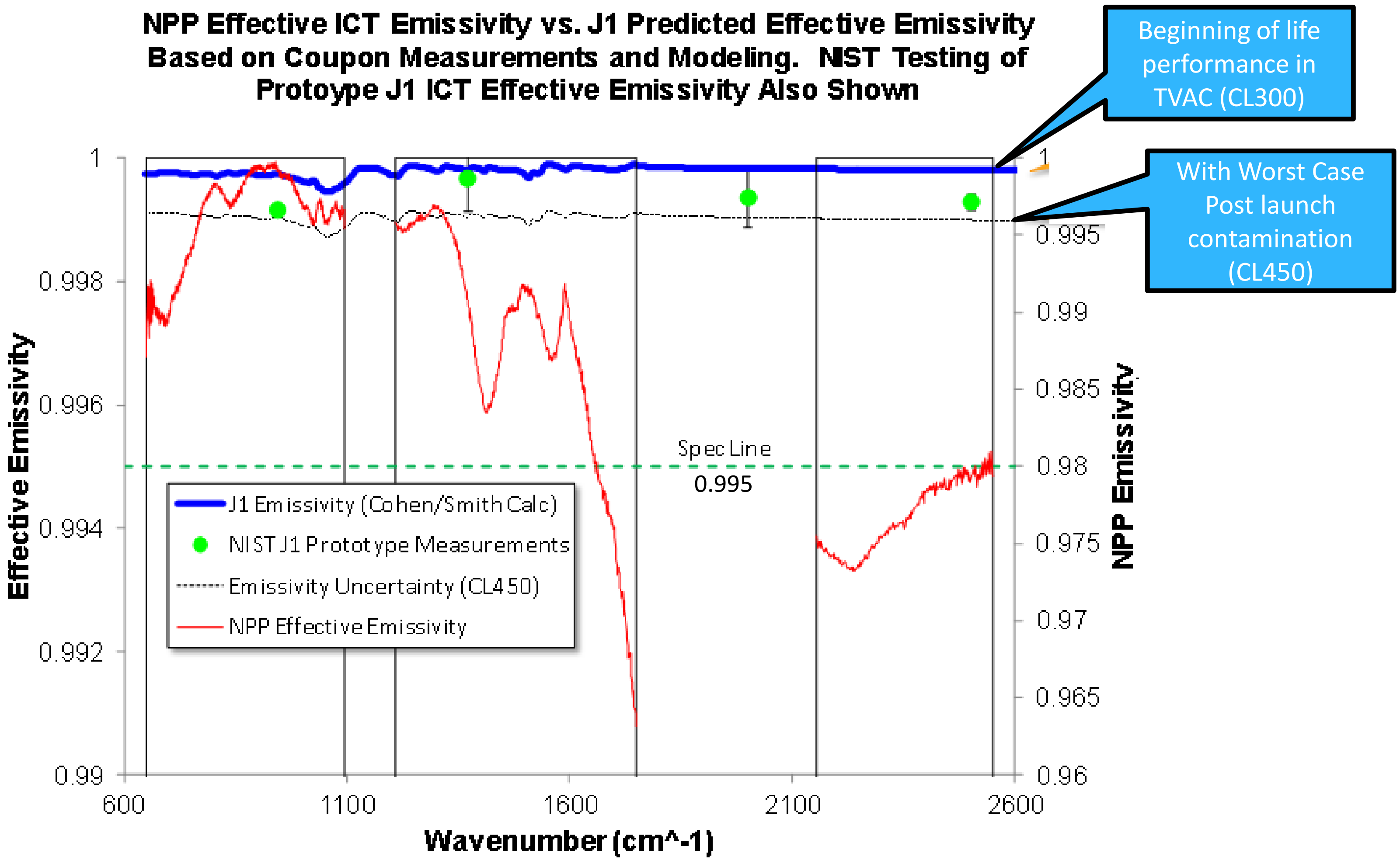
Improved Internal Calibration Target (ICT) Is Deployed on CrIS J1 Instrument

- Specular 3-bounce trap blackbody design
- Largely immune to stray light from surrounding environment
- Instrument sees radiance from ICT plus a very dim reflected image (<0.5%) of itself which is accounted for in SDR radiance modeling
- ICT temperature uncertainty much lower





J1 Instrument ICT Emissivity Significantly Improved Over NPP Instrument



Better ICT Stray Light Rejection Results in Elimination of Numerous Reflected Error Sources

- **Benefits**
  - **45° ICT cavity angle causes off-axis stray light entering ICT to leave ICT off-axis**
  - **More accurate calibration performance because many sources of radiance uncertainty have been eliminated**
  - **Simplified SDR processing**

Radiance Error Sources That No Longer Need to Be Modeled for JPSS

<table>
<tr><th>View From</th><th>To</th><th>Fractional View to Environment (NPP)</th><th>Fractional View to Environment (J1 and up)</th></tr>
<tr><td>ICT Base</td><td>ICT Walls</td><td>0.000</td><td>0.000</td></tr>
<tr><td>ICT Base</td><td>ICT Base</td><td>0.000</td><td>0.000</td></tr>
<tr><td>ICT Base</td><td>ICT Baffle</td><td>0.175</td><td>0.000</td></tr>
<tr><td>ICT Base</td><td>Scan Baffle</td><td rowspan="2">0.508</td><td rowspan="2">0.000</td></tr>
<tr><td>ICT Base</td><td>Scan Mirror</td></tr>
<tr><td>ICT Base</td><td>Frame</td><td rowspan="2">0.214</td><td rowspan="2">0.000</td></tr>
<tr><td>ICT Base</td><td>Opto-Mechanical Assembly (OMA)</td></tr>
<tr><td>ICT Base</td><td>Warm Beamsplitter</td><td>0.086</td><td>0.000</td></tr>
<tr><td>ICT Base</td><td>Cold Beamsplitter</td><td>0.008</td><td>1.000</td></tr>
<tr><td>ICT Base</td><td>Space</td><td>0.009</td><td>0.000</td></tr>
</table>

Only Remaining Term to Model

Four Error Categories Contribute to CrIS J1 ICT Radiometric Error

39 mK ICT Temperature Uncertainty Dominates (WC EOL)

% Uncertainty Relative to a 287 K Black Body Radiance

ICT Radiance Uncertainty		
Band	EOL	BOL
LWIR	0.121%	0.083%
MWIR	0.158%	0.121%
SWIR	0.217%	0.177%

RSS

39 mK (1 sigma) RSS Temperature Error Dominates ICT Radiometric Uncertainty

Radiance Uncertainty Due to Diffuse ICT Reflections		
Band	EOL	BOL
LWIR	0.01%	0.01%
MWIR	0.03%	0.03%
SWIR	0.04%	0.04%

- EOL contamination (CL 450)
- ICT external environment temperature difference (4.5 K)

Radiance Uncertainty due to Emissivity Knowledge		
Band	EOL	BOL
LWIR	0.05%	0.03%
MWIR	0.04%	0.02%
SWIR	0.05%	0.03%

- Includes effect of SDR environmental model correction
- Specular emissivity uncertainty
  - NIST coupon characterization
  - Emissivity uniformity (FOV)
  - Target vignetting
  - EOL contamination (CL 450)
  - EOL paint aging

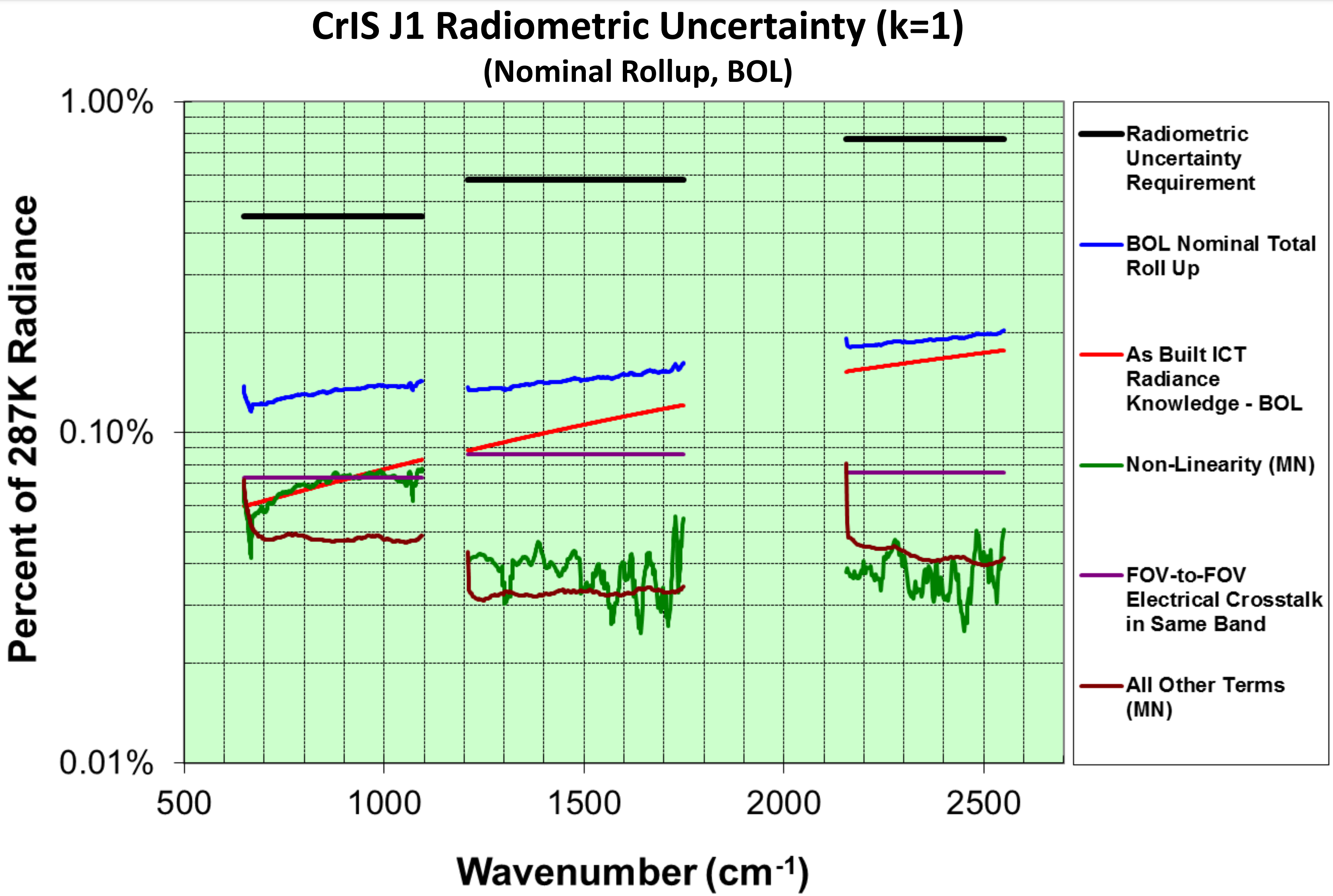
Radiance Uncertainty Due to ICT Temperature Error		
Band	EOL	BOL
LWIR	0.07%	0.07%
MWIR	0.12%	0.12%
SWIR	0.17%	0.17%

- PRT calibration 17.5 mK
- Electronic readout 12.5 mK
- PRT electrical bias error 11 mK
- Temperature gradients
  - Lateral FOV to FOV) 12 mK
  - Axial (paint worst case) 28 mK
- Other 3 mK

Radiance Uncertainty Due to Unmodeled ICT External Environment		
Band	EOL	BOL
LWIR	0.08%	0.02%
MWIR	0.09%	0.01%
SWIR	0.11%	0.01%

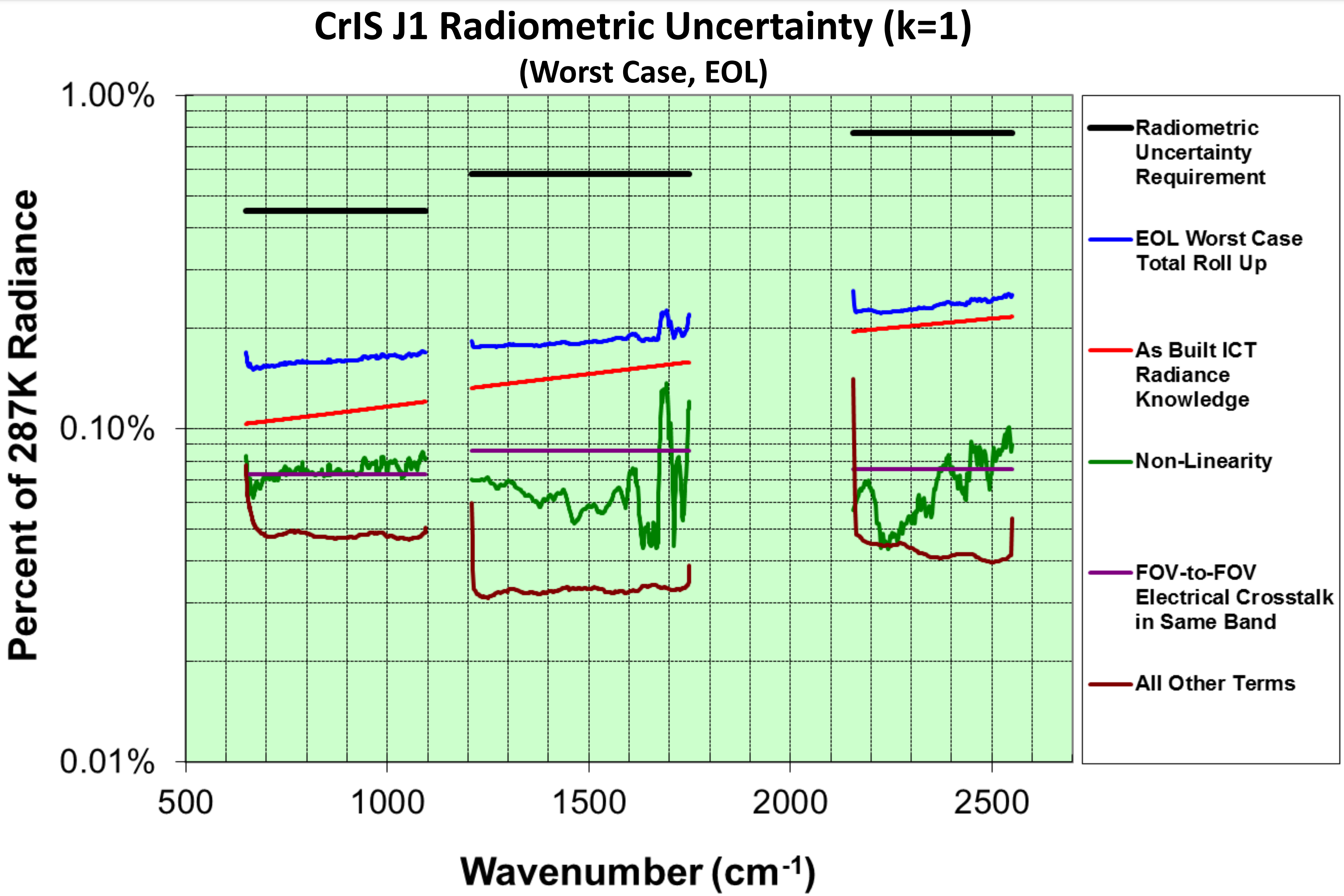
- Unmodeled reflection from CrIS instrument
  - Beamsplitter emission
  - Aft optics emission
  - FTS mirror emission
- EOL contamination (CL 450)

CrIS Internal Calibration Target (ICT) Remains the Dominant Source of Radiometric Uncertainty



Same Holds True for Mission Worst Case End-of-Life (EOL)

(Only a modest Degradation estimated from BOL to EOL)

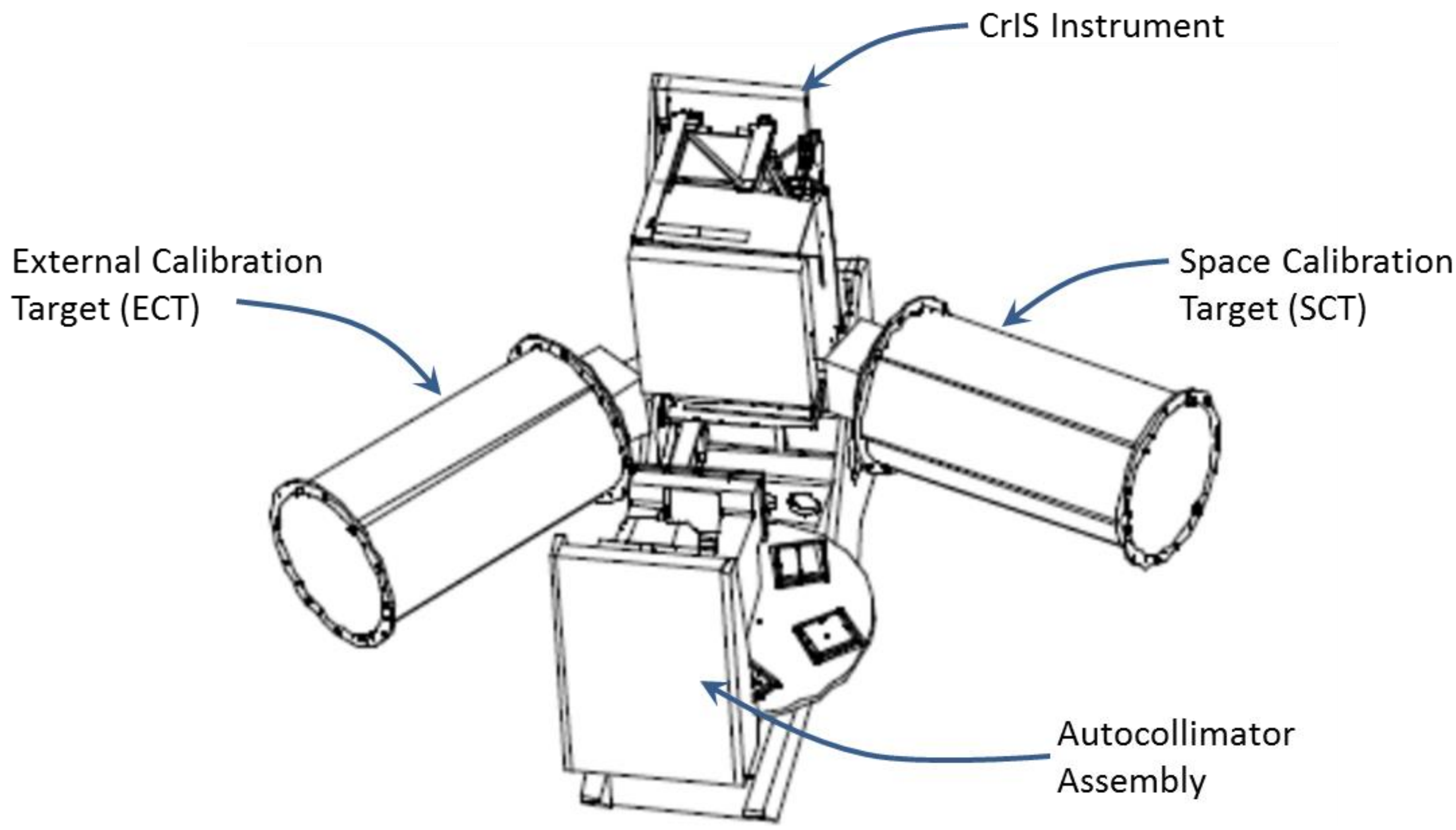


CrIS J1 ICT Radiometric Performance Is Climate Trending Class. How Can This Be Validated During TVAC?

- **CrIS ICT Radiometric Performance Expected**
  - **>0.9995 emissivity (specular)**
  - **39 mK (1 sigma) temperature uncertainty predicted (worst season on-orbit)**
  - **24 mK (1 sigma) temperature uncertainty predicted (during TVAC)**

External Calibration Target (ECT) & Space Calibration Target (SCT) Used to Verify Radiometric Performance During TVAC

Test Configuration Inside TVAC Chamber



External Calibration Target (ECT) Role in CrIS Testing

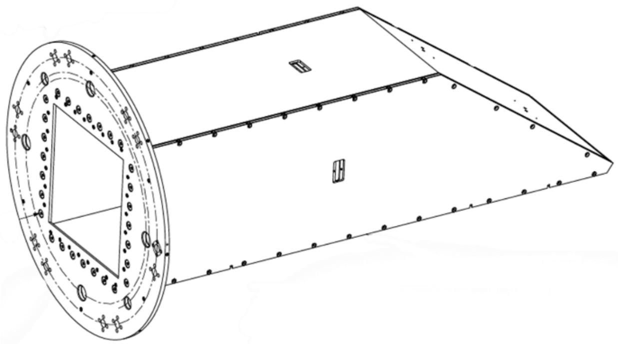
- **ECT Is Essential in Four Instrument Tests**
  - **NEdN characterization**
  - **Validation of radiometric responsivity vs. wave number**
  - **Validation of long term (30 day) radiometric stability**
  - **Radiance source for radiometric linearity characterization**

- **ECT NOT Used to “Calibrate” CrIS…………..ECT used only for validation**
  - **CrIS radiometric calibration is derived only from ICT**
  - **NIST traceable temperature calibration is via…**
    - **ICT PRTs with NIST-traceable temperature calibration**
    - **Two precision NIST traceable resistors used to compare with each PRT’s temperature dependent resistance**
    - **Algorithm using PRT-specific coefficients & pre-launch precision resistor values**
    - **Long term PRT & precision resistor stability built into CrIS**

ECT Is a Full Aperture 5 Bounce Specular Target
(non-uniform temperature is primary limitation)

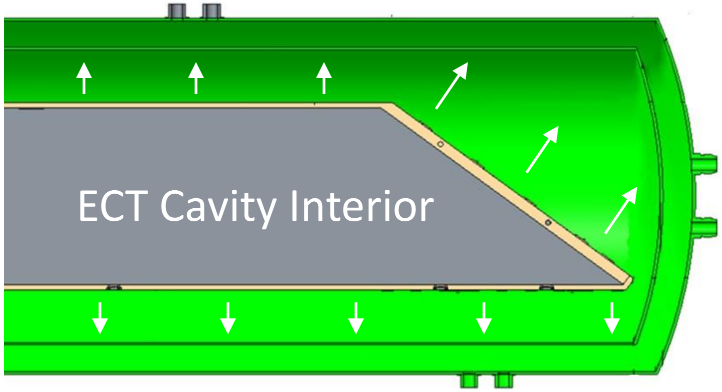
- **ECT Characteristics TVAC Testing (as originally designed)**
  - >0.9995 emissivity (specular)
  - Temperature uncertainty
    - 100 mK (1 sigma) (design requirement)
    - 70 mK (1 sigma) analysis

ECT 3D View



- **Issues During TVAC**
  - Temperature readout error high as 150 mK at start of TVAC due to electronic instrumentation issues
  - ECT was 12 years old……..so were most of the PRT calibrations
  - Large thermal gradients present within ECT
    - Caused by LN_2 cooled heat sink combined with high power heaters used for thermal set point control
    - Up to 500 mK temperature gradient through thickness of ECT primary target plate
    - Up to 400 mK temperature gradient along length of ECT primary target plate

Cross Section of ECT Inside LN_2 Dewar

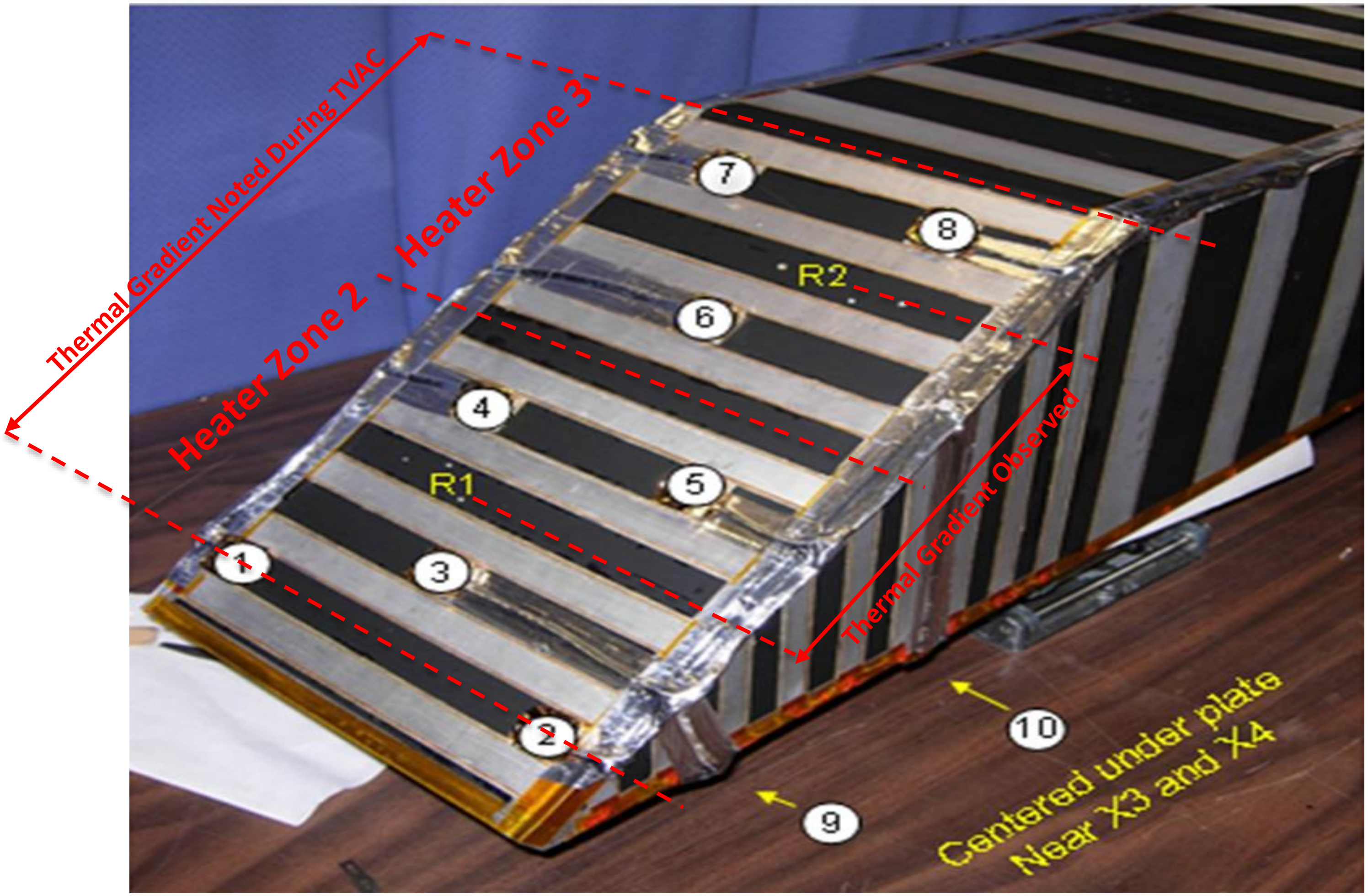


Purpose of ECT Calibration Enhancement Is to Reduce ECT Radiometric Uncertainty

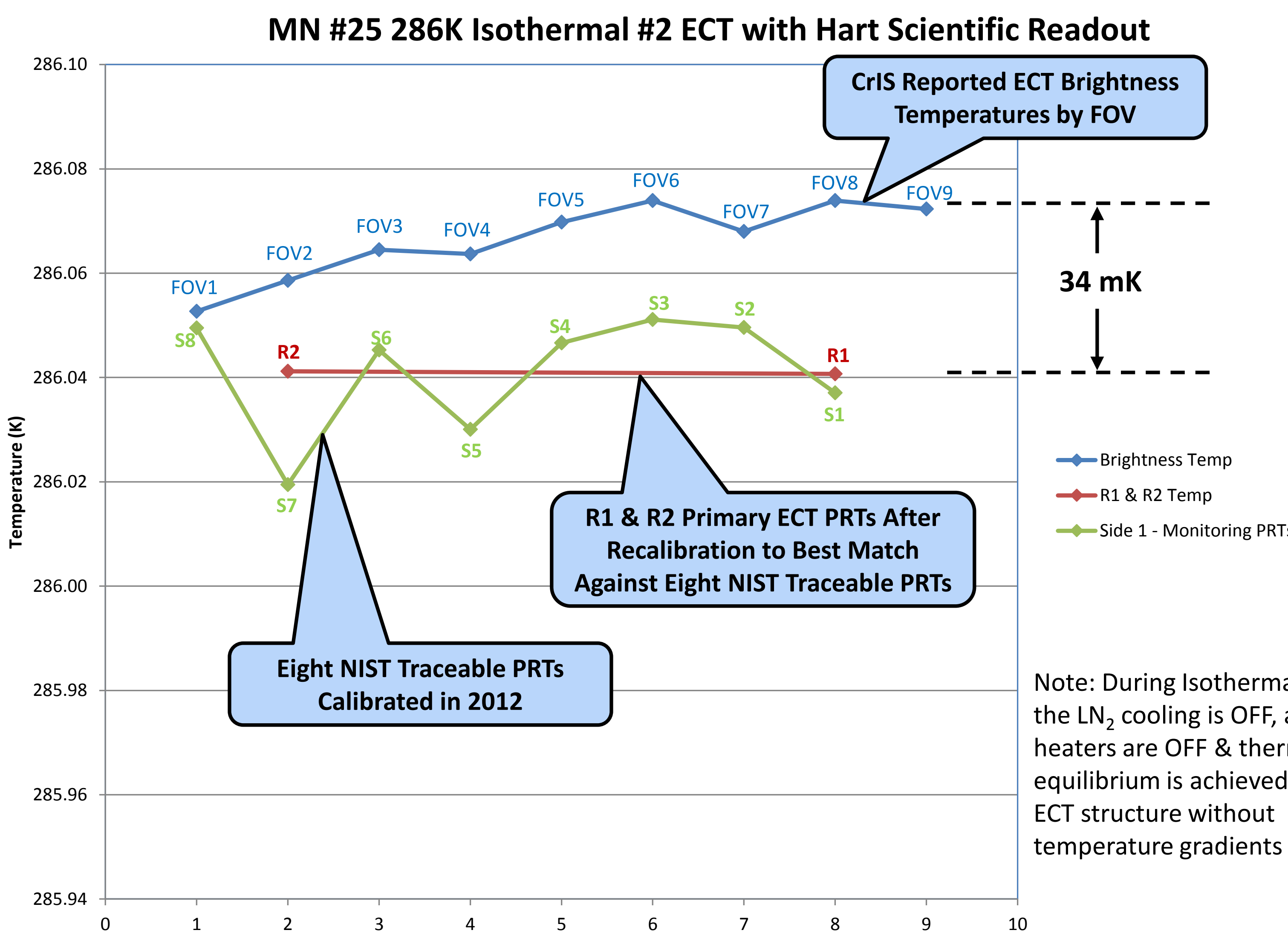
- **Objective**
  - Determine the temperature bias of all ECT PRTs relative to the R2 PRT primary temperature reference
  - Anchor all ECT PRT temperature calibrations to the 8 monitor PRTs mounted on the ECT primary wedge plate surface that were calibrated against multiple NIST references in 2012
  - Characterize and remove electronic readout error of ECT PRTs
  - Use results to calculate a more accurate ECT radiance for TVAC acceptance testing
- **Method**
  - Perform multiple isothermal ECT tests that can be used to determine relative PRT temperature offsets under a uniform temperature condition
  - Use a high precision readout meter for at least one of the isothermal tests so that relative bias errors can be fully attributed to aged PRT calibration coefficients
  - Use isothermal test with high precision electronic readout to anchor PRT R1 & R2 reported temperatures to the family of 8 monitor PRTs mounted on ECT wedge plate
  - Use 10 ohm, 25 ohm and 100 ohm precision NIST traceable resistor references to calibrate meters used during TVAC testing

Eight Externally Mounted PRTs with 9 mK NIST Traceable Uncertainty Were Used to Re-establish Temperature Calibration

- R1 & R2 PRT are primary temperature sensors
- S1 through S8 PRTs used for calibration enhancement under isothermal conditions



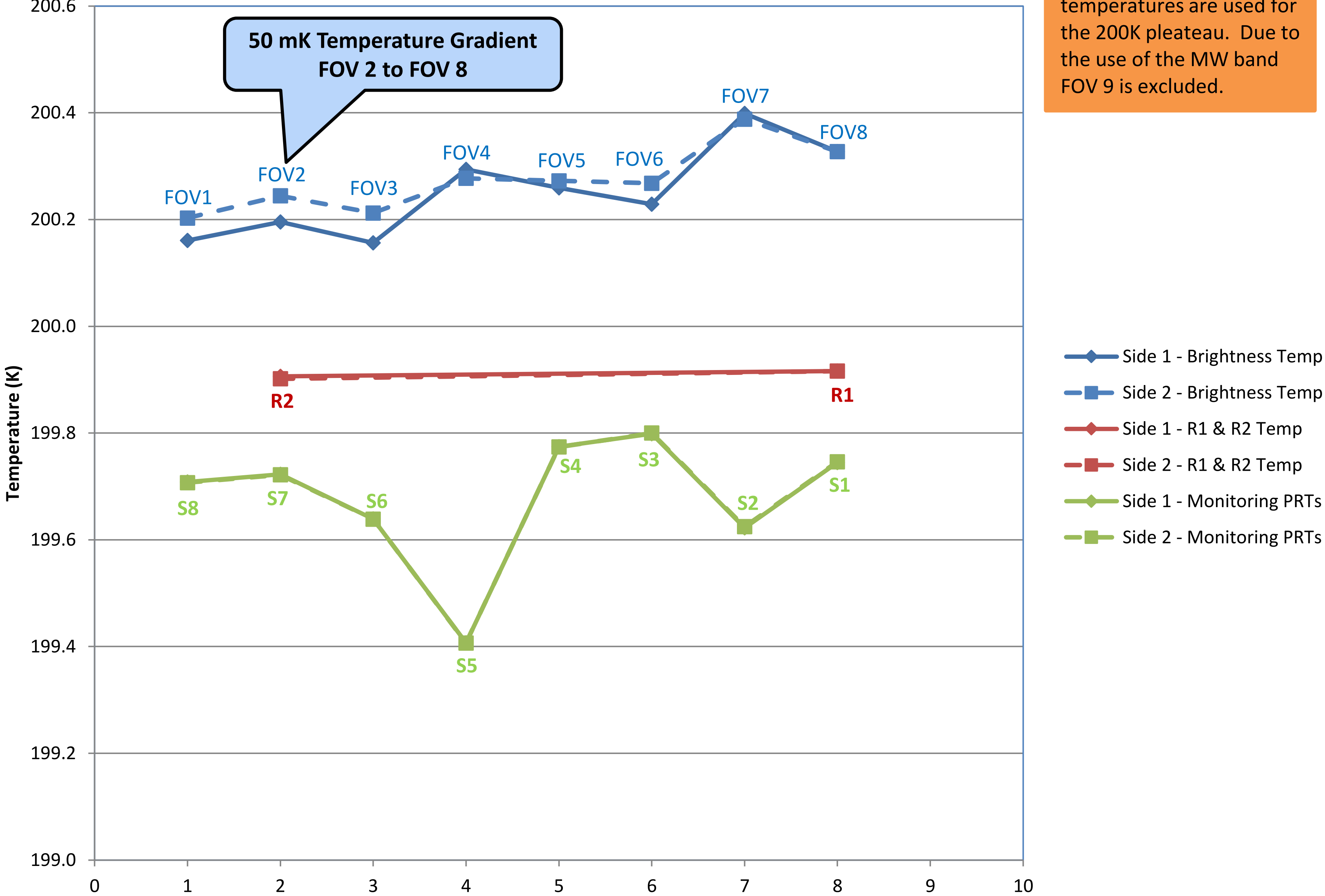
ICT & ECT Temperatures Matched within 34 mK During TVAC Isothermal ECT Test Conducted at Mission Nominal



Note: During Isothermal testing, the LN_2 cooling is OFF, all ECT heaters are OFF & thermal equilibrium is achieved across ECT structure without temperature gradients present

Thermal Gradients Were Still Present on ECT During Normal TVAC Testing

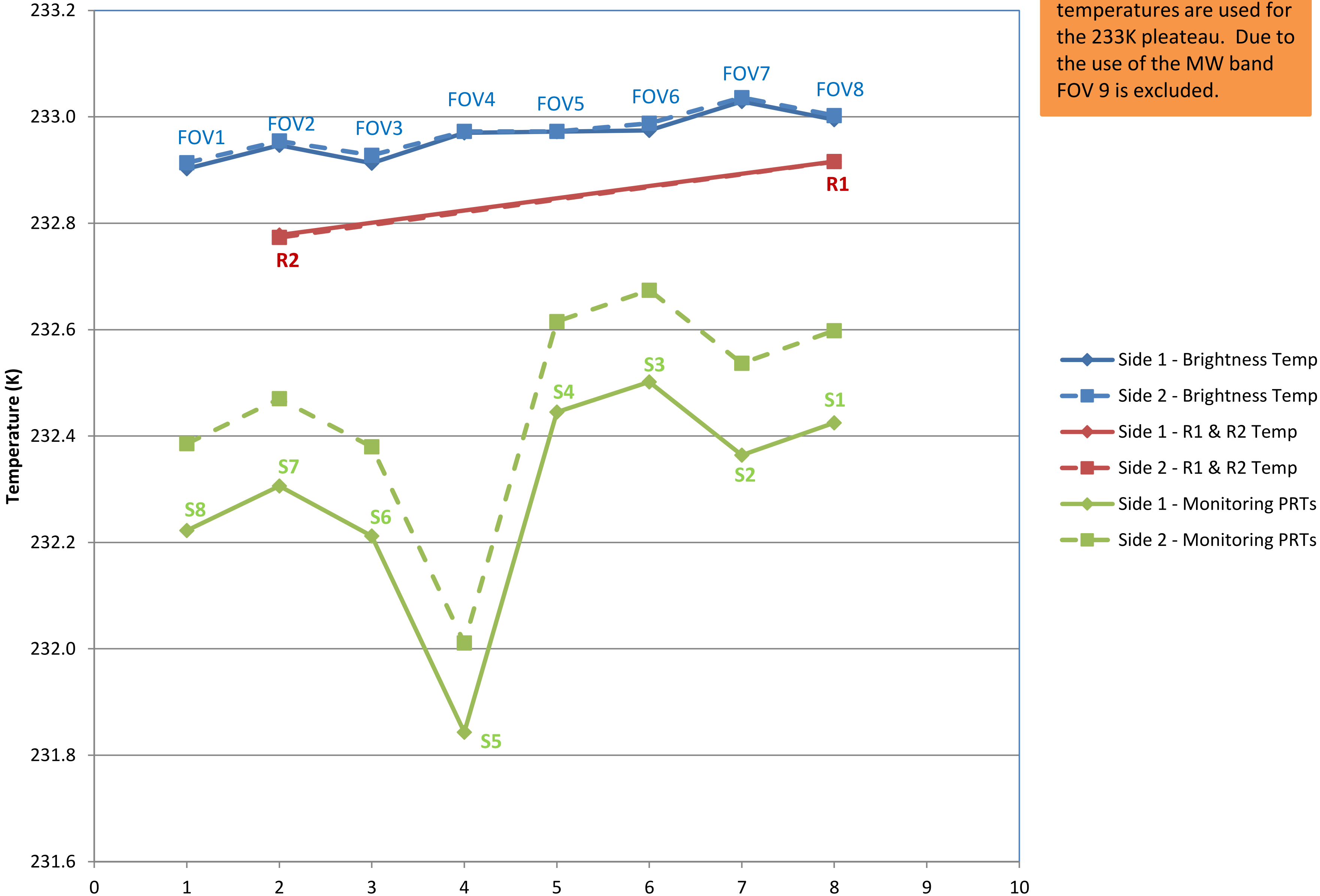
MN 200K ECT Plateau

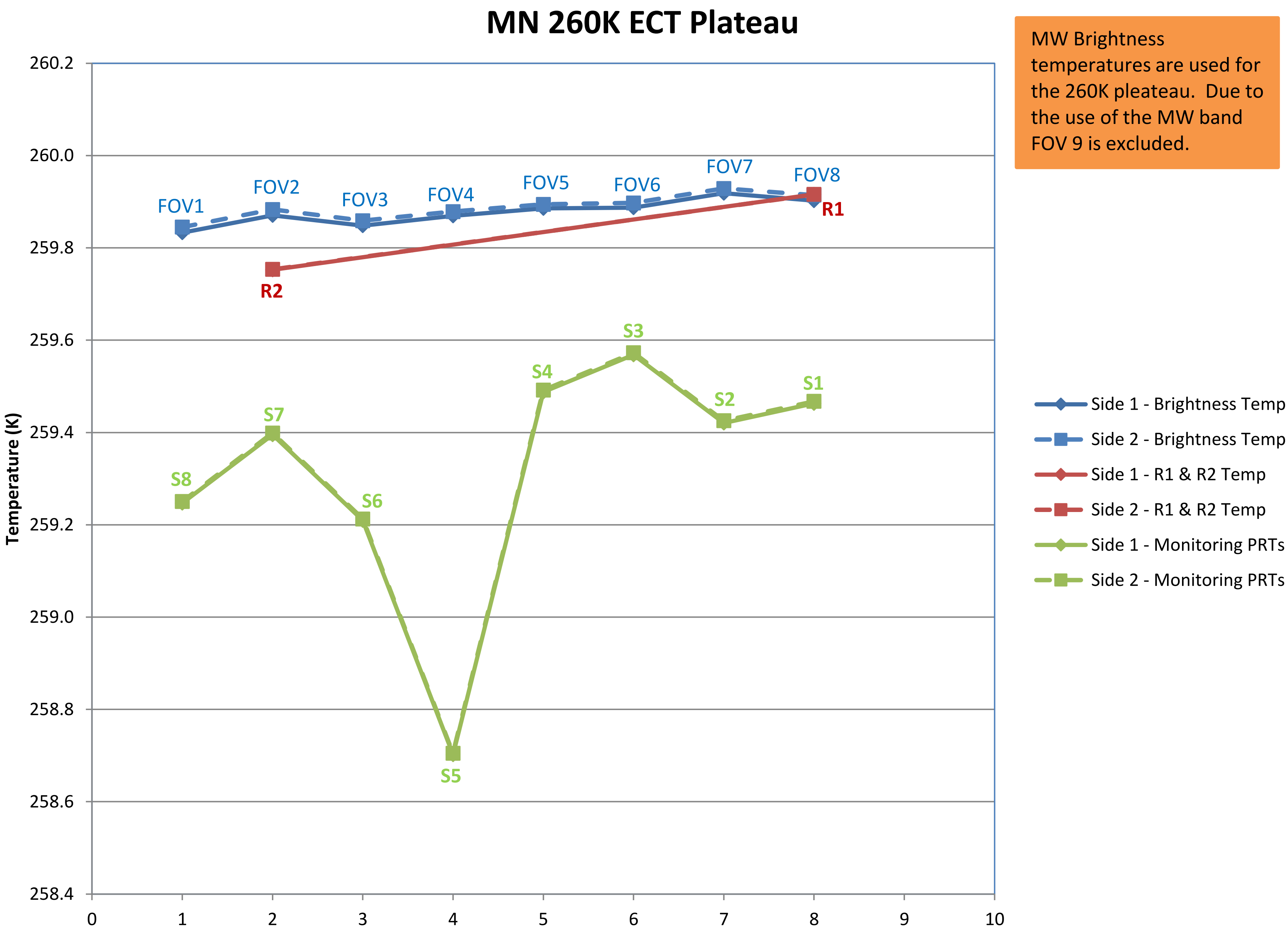


MW Brightness temperatures are used for the 200K pleateau. Due to the use of the MW band FOV 9 is excluded.

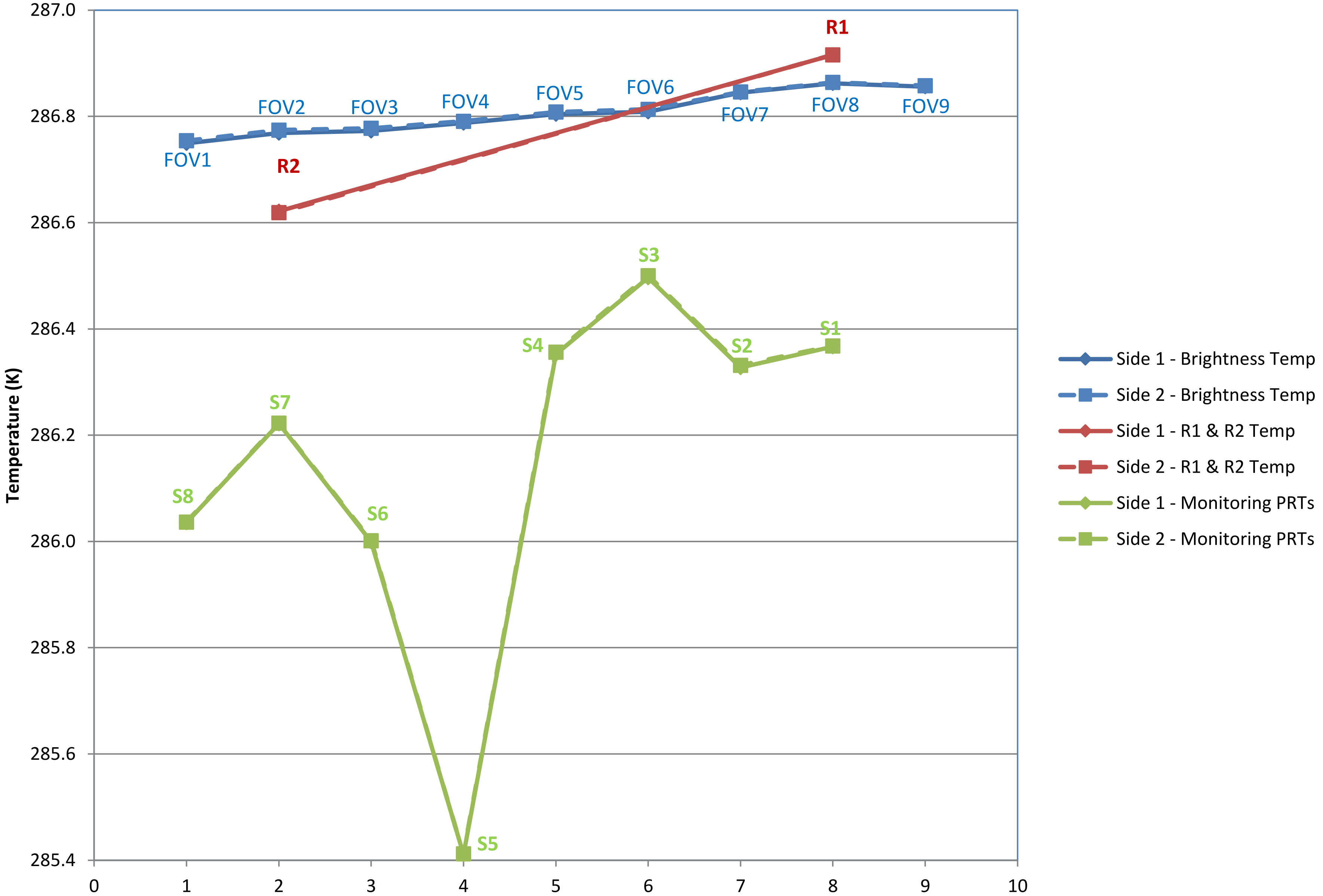
MN 233K ECT Plateau

MW Brightness temperatures are used for the 233K pleateau. Due to the use of the MW band FOV 9 is excluded.

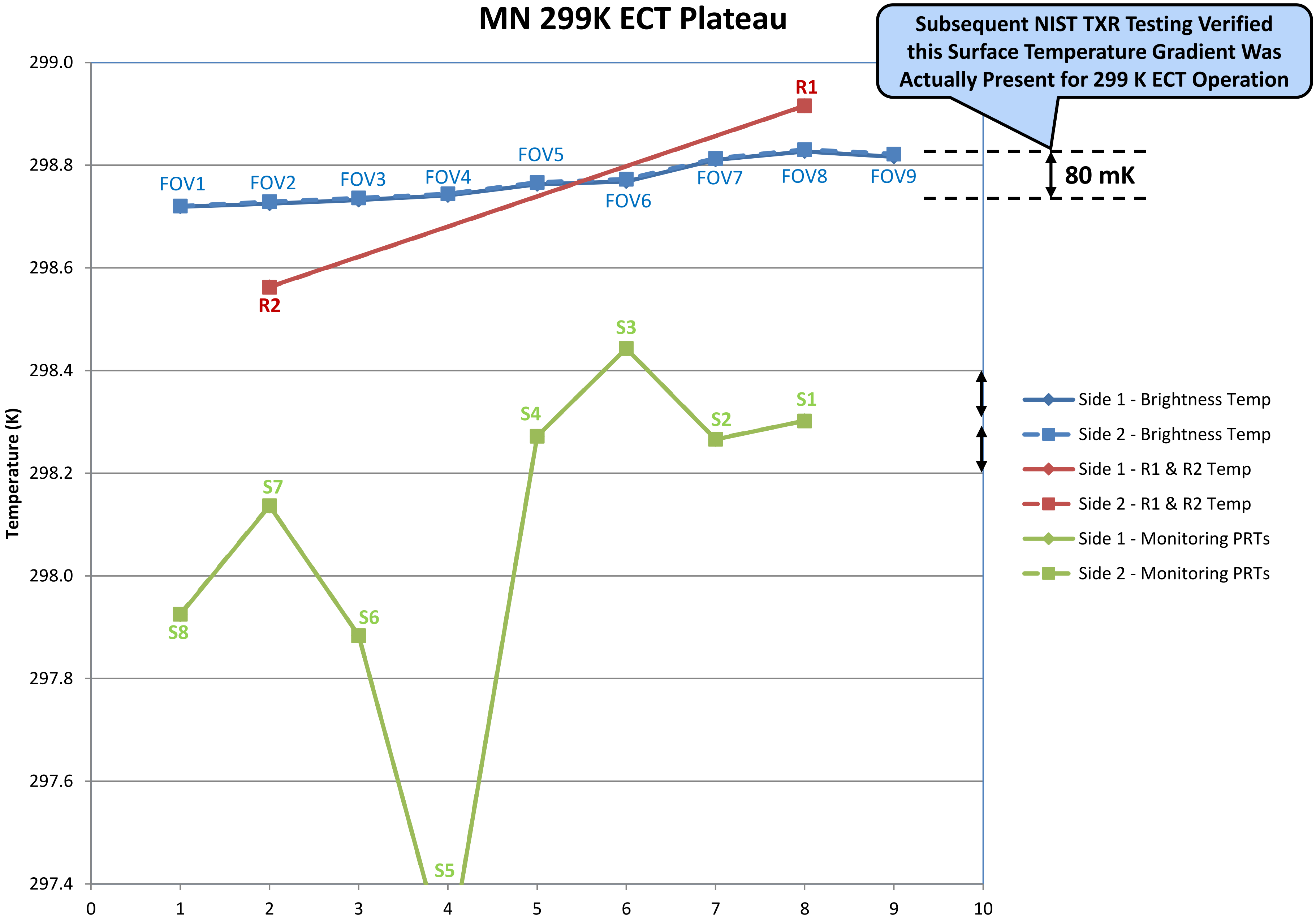



MN 260K ECT Plateau
MW Brightness temperatures are used for the 260K pleateau. Due to the use of the MW band FOV 9 is excluded.
Temperature (K)
260.2
260.0
259.8
259.6
259.4
259.2
259.0
258.8
258.6
258.4
0
1
2
3
4
5
6
7
8
9
10
FOV1
FOV2
FOV3
FOV4
FOV5
FOV6
FOV7
FOV8
R1
R2
S8
S7
S6
S5
S4
S3
S2
S1
Side 1 - Brightness Temp
Side 2 - Brightness Temp
Side 1 - R1 & R2 Temp
Side 2 - R1 & R2 Temp
Side 1 - Monitoring PRTs
Side 2 - Monitoring PRTs

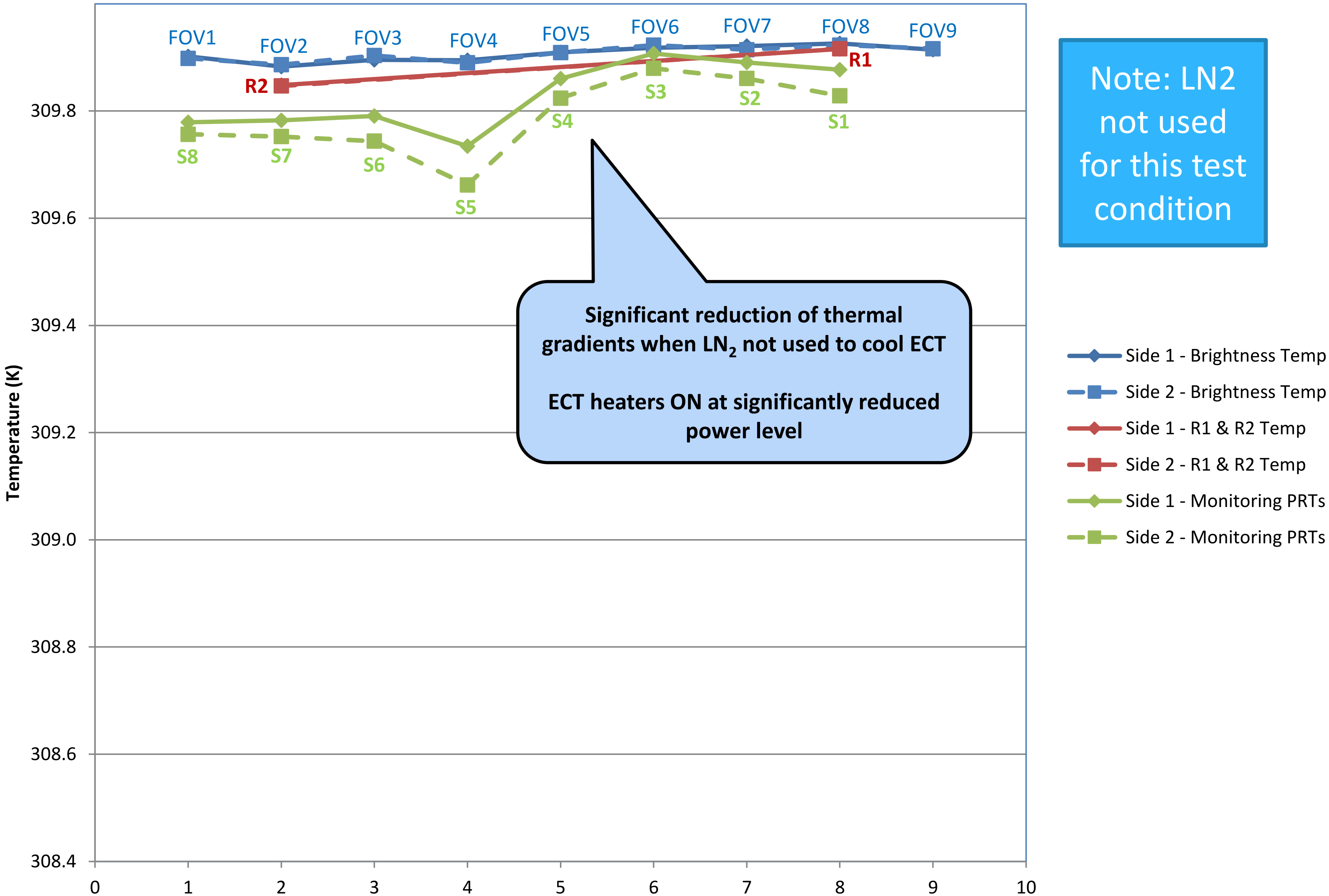
MN 287K ECT Plateau



MN 299K ECT Plateau



MN 310K ECT Plateau



Substantially Improved ECT Design for Future J2 TVAC Testing Believed Possible & Would Be Beneficial

(1 of 3)

- **Desired Objectives**
  - **Temperature uncertainty knowledge……….. 30 mK (1 sigma)….NIST traceable**
    - **ECT portion of budget……………………………….28 mK**
    - **Electronic readout portion of budget………..10 mK**
  - **Maximum temperature gradient (primary plate) ………… 45 mK**

- **Promising Concept Under Investigation at Harris for J2 TVAC**
  - **LN_2 cooling replaced by variable temperature circulator**
  - **ECT cavity is directly liquid cooled near ECT input aperture…….does not rely on radiative cooling**
  - **Regulate temperature slightly above liquid cooled heat sink temperature using <u>low power</u> heaters**

TVAC ECT Instrumentation Was Augmented By Analysis to Provide Meaningful Validation of CrIS Radiometric Calibration

- **ECT Performance Enhancements for Radiometric Calibration**
  - **PRT electronic readout errors eliminated using NIST traceable calibration resistor references**
  - **Primary ECT temperature sensor (R1 & R2) calibration re-establish using eight NIST traceable PRT references (9 mK uncertainty) during an ECT isothermal test**
  - **Three ECT isothermal tests spanning CrIS J1 TVAC performed to demonstrate ECT temperature knowledge stability (R1 & R2) with only a 26 mK discrepancy noted**

Results

- **ECT & ICT temperature calibration match to within 34 mK**

TVAC ECT Instrumentation Is Augmented By Analysis to Provide Meaningful Validation of CrIS Radiometric Calibration

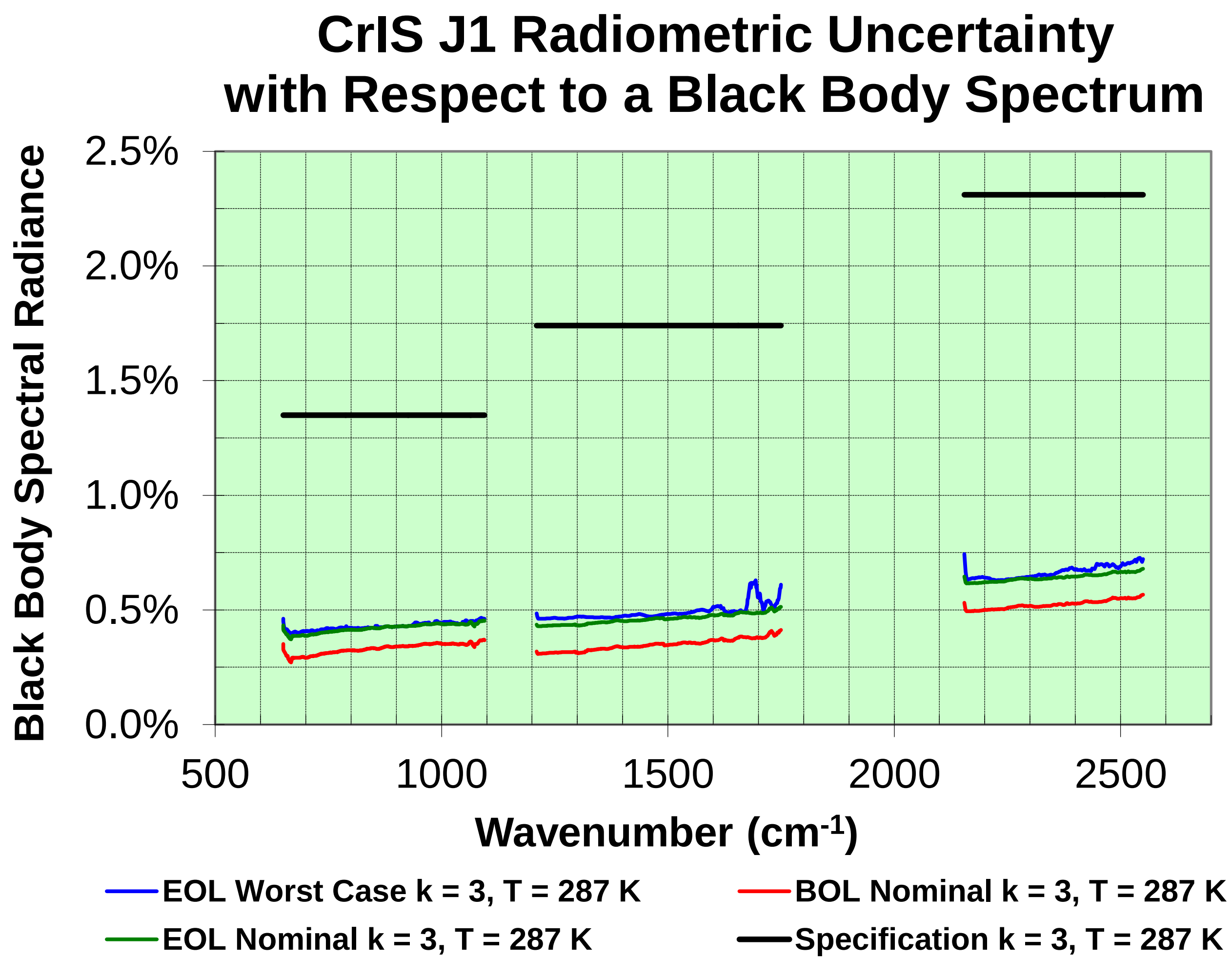
- **ECT Thermal Gradients Removed Analytically in TVAC Data Analysis**
  - **NIST Transfer Radiometer (TXR) verified ECT thermal gradients match brightness temperatures reported by CrIS in all FOVs (299 K test result)**
  - **CrIS SWIR & MWIR linear detectors used to map ECT surface temperature gradients when collecting data at each ECT set point temperature (200 K, 233 K, 265 K, 287 K, 299 K & 310 K)**
  - **Correct ECT reported temperature by FOV for radiometric analysis**

Results

- **LWIR & MWIR linearity testing can use ECT source with enhanced surface temperature knowledge that accurately accounts for thermal gradients**

Radiometric Uncertainty Relative to NEdT Performance

CrIS J1 Radiometric Uncertainty (k = 3) for 287 K Scene



Radiometric Uncertainty Gain Factors

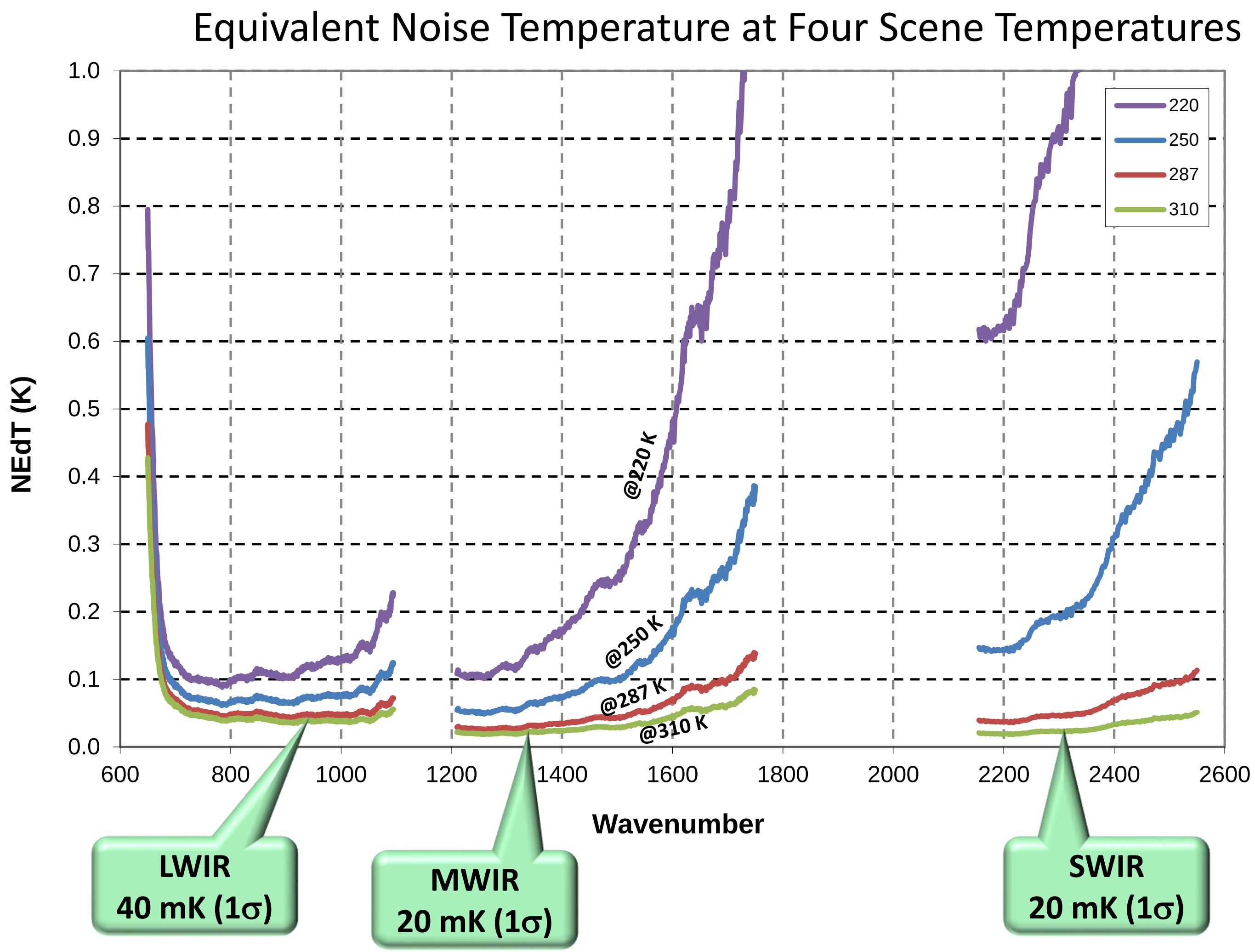
- Detector Temperature Changes Over 4 Minutes
- Changes in DA Bias Tilt Over 4 Minutes
- Changes in Optical Flatness Over 4 Minutes
- Polarization Change ICT to Scene
- As Built ICT Radiance Knowledge
- As Built ICT Radiance Knowledge - BOL
- Non-Linearity
- Non-Linearity (MN)
- Electronic Delay Drift Over 4 Minutes
- Electronic Gain Drift Over 4 Minutes
- Changes in Channel Spectra Over 4 Minutes
- OPD Sampling Rate Drift Over 4 Minutes
- Other Small Effects

Radiometric Uncertainty Offset Factors

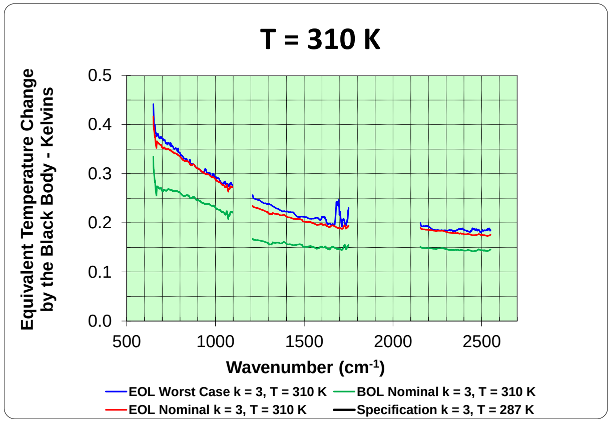
- Polarization Effects (Offset)
- Optics Temperature Changes Over 4 Minutes
- FOV-to-FOV Electrical Crosstalk in Same Band
- ~~FOV-to-FOV Crosstalk Between Bands~~
- FOV-to-FOV Crosstalk Between Bands (MN)
- Solar Scattering JPSS Orbit

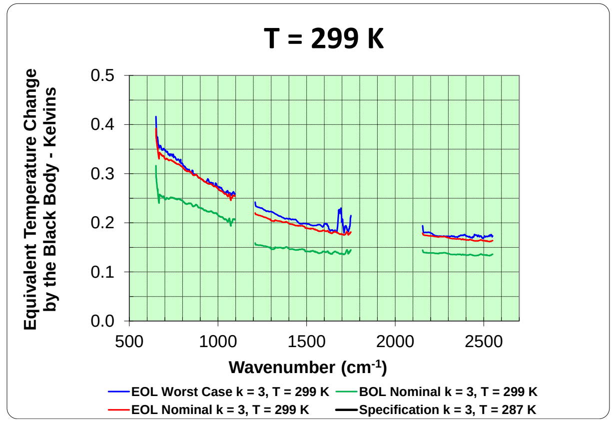
Modified (1) CrIS J1 Radiometric Unc & Long Term Stability Roll-Ups (EOL & BOL) - 081715 rjh v12.xlsx

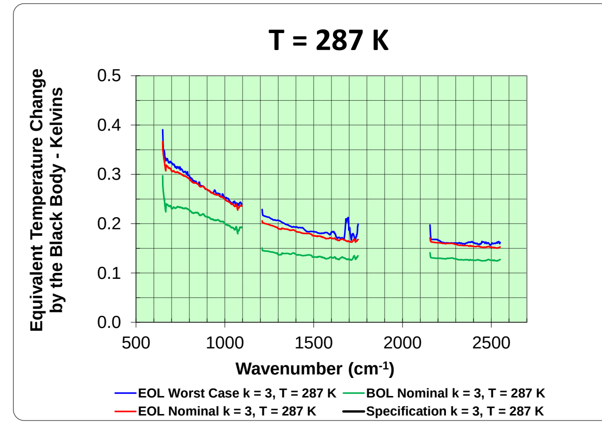
Typical CrIS Noise Temperature Plots
(from Suomi NPP ……… J1 CrIS Is Similar)

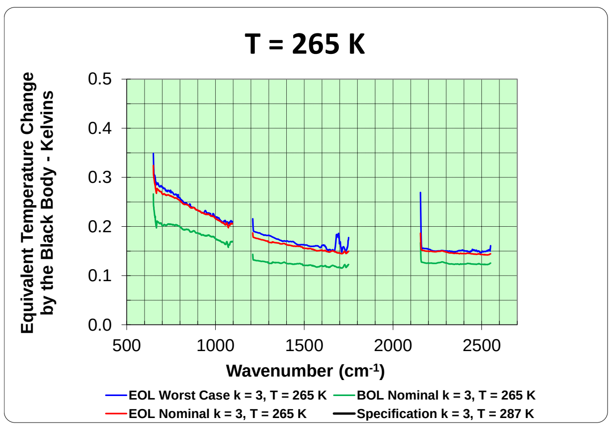


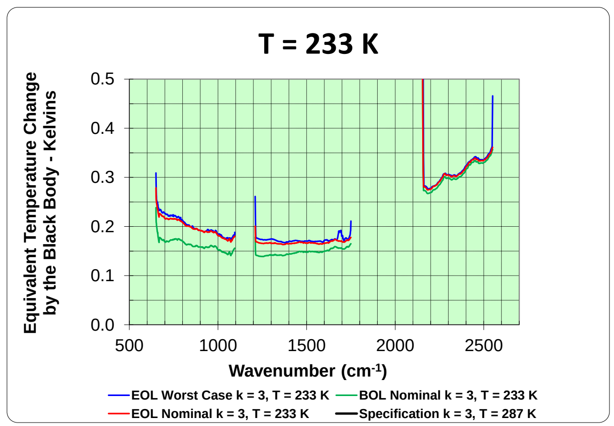
CrIS J1 Radiometric Temperature Uncertainty Estimates (k = 3) for Various ECT Black Body Scene Temperatures

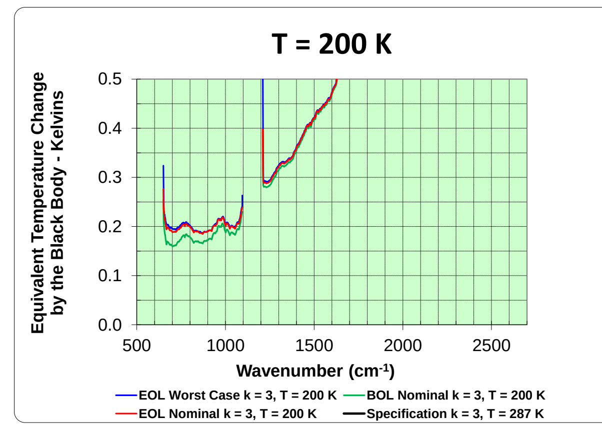












CrIS Noise Performance (NEdT, k=1) Is Small
Compared to the Radiometric Uncertainty Equivalent Temperature Error (k=3)

Modified (1) CrIS J1 Radiometric Unc & Long Term Stability Roll-Ups (EOL & BOL) - 081715 rjh v12.xlsx